ARS SPECIAL REPORT

Gibberellic Acid

An Unusual Plant-Regulating Chemical

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SUMMARY

What is gibberellic acid?

Gibberellic acid is a chemical which can change plant growth and development in varied ways, suggesting agricultural uses. It is a natural product of an Asian fungus.

How is gibberellic acid produced?

The fungus is grown in a nutrient solution, and the acid obtained from the liquid--much the way penicillin is produced.

How is gibberellic acid applied to plants?

It is most conveniently applied in a very dilute spray solution made with water and the addition of a suitable detergent, and sometimes alcohol, to improve solubility. An alternate method is to apply the acid to stems in a lanolin paste.

How does the chemical affect plants?

Rapid lengthening of stems for a few weeks is a common response. However, from selected tests on about 50 kinds of economic plants, ARS scientists noted as many as 17 changes. Results depended on strength of treatment, plant species, stage of development. Plants flowered faster--or slower; grew thinner or thicker stems; developed more foliage or more seed; overcame dwarfism; roused from dormancy. Few plants were unaffected.

What economic uses are foreseen for this chemical?

Among many uses suggested--it might speed seed production; lengthen stems of low-growing crops to allow better weed control; improve ornamentals and adjust their flowering to timed markets; speed slow timber growth.

How far has gibberellic acid advanced in practical use?

Commercial firms have conducted, and are conducting, research to develop specific uses for gibberellic acid, and trade-marked products are on the market. The Agricultural Research Service, however, considers gibberellic acid an experimental material, and its research results to date have not been conclusive enough to provide a basis for recommended use.

How can gibberellic acid be obtained?

Commercial products are usually stocked with garden supplies.

Are there precautions for use of this chemical?

Yes. Public and private research has shown that overdosage may induce weak, rank growth and can damage plants; that an above-ground growth spurt of treated plants tends to be associated with slower root growth. Therefore, young plants may need a week or two before treatment to establish some roots. Don't expect the growth stimulator to be a substitute for plant nutrients, sunlight, or moisture. Treated plants may need more fertilizer, not less. In view of research findings, and the fact that commercial formulations may vary in regard to the type and proportion of gibberellins, ARS scientists suggest that persons wishing to try commercial products should carefully follow the manufacturer's directions regarding use.

Information in this report was provided by the Crops Research Division and the Soil and Water Conservation Research Division, Agricultural Research Service

GIBBERELLIC ACID--

AN UNUSUAL PLANT-REGULATING CHEMICAL

An unusual plant-regulating chemical known as gibberellic acid (the g is sounded like j) is being widely studied by scientists and is attracting much public attention because it can change plant growth in varied, often striking ways.

Plants experimentally treated with gibberellic acid have grown taller stems and often thinner stems--compared with untreated plants--though sometimes the thin stems have thickened later. Treated plants have flowered faster--or slower; produced more abundant foliage or more seed; overcome dwarfism; even roused from dormancy to start growth in unusual times and conditions. From selected tests on about 50 kinds of economic plants, scientists in the Agricultural Research Service noted as many as 17 different changes among treated plants.

For the time being, gibberellic acid is mainly experimental. Many economic uses have been suggested for a substance so versatile. It might conceivably be used, for example, to--

* Advance growth of a crop that must be brought to harvest in a short growing season.

* Heighten a low-growing crop enough to facilitate some types of weed control.

* Improve ornamentals and speed their flowering to meet timed markets.

* Improve forage yields.

* Overcome scarcity of some crop seed.

* Speed the production of slow-growing timber.

A chemical that can change plant growth and development in many ways obviously poses complex problems for research. Stem-lengthening--the most characteristic effect of the acid--is easily induced in most plants. But gaining some flowering effect, for example, without stem-lengthening or another unwanted side-effect may be harder or perhaps not possible. Furthermore, results have varied with the plant treated, with the amount of gibberellic acid applied, with the timing of treatment, and even with some growing condition, such as temperature or light.

The natural source of gibberellic acid is an Asian fungus called Gibberella fujikuroi. The research history of the acid began in the Orient, where Japanese scientists did pioneer work on the Gibberella fungus for many years with slight recognition abroad. From their findings came the first knowledge of a stem-lengthening product of the fungus. The varied effects of gibberellic acid have been studied and applied in recent years by scientists in many countries.

An ARS Division developed a practical method of producing a quantity supply of the chemical. And the ARS is now sharing with other research

agencies in experimental work to determine values that gibberellic acid may have for making economic plants more profitable and plant products more useful.

Currently, ARS scientists have not formulated any recommendations on specific gibberellic acid uses. It is clear that treatments warranting agricultural use must give dependable results in specific plant growing situations, and must be economically feasible. Any ultimate favorable or unfavorable effects on nutritional qualities of food and feed plants remain to be established. A grower who wishes to try gibberellic acid should follow closely a manufacturer's directions for the product, recognizing that unwise usage can bring unwanted changes and possible damage to plants.

HIGHLIGHTS OF RESEARCH HISTORY

Some highlights of the discovery and development of gibberellic acid are given below, primarily to explain points about which questions are frequently raised: How gibberellic acid came to be separated from its association with a Far Eastern plant disease; why the Western World knew so little about Eastern research in this field for many years; why different names for gibberellic acid are sometimes encountered in descriptive accounts.

Pioneer Research in Japan

In 1898 a Japanese botanist published the first scientific description of a fungus disease that was seriously reducing Far Eastern rice crops. Farmers called the disease "bakanae"--foolish seedling--because infested rice plants grew long, threadlike stems and eventually died from combined weakness and parasite damage. The report attributed the disease to a fusarium type of fungus. Later, the fungus was named Gibberella fujikuroi. For years, Japanese researchers grew the fungus in nutrient solutions to study its characteristics as one approach to combating its damage.

In 1926 curiosity led a Japanese scientist to test an idea that the fungus, in its mold growth stage, might secrete some chemical which caused the overgrowth trait in bakanae-diseased rice. He filtered the pink-purple mold off a Gibberella culture solution, boiled the remaining liquid and applied it to rice plants. The sterile liquid did cause the stems to lengthen.

This discovery led Japanese researchers to attempt to isolate the specific stem-lengthening substance from filtrate solutions. This task proved difficult. When the first pure crystals were isolated in 1934, they were not the expected stem-lengthening agent. Instead, the substance retarded stem growth, and it was evident that strains of the Gibberella fungus could produce more than one plant regulating substance. Four years later, a Japanese research team announced success in isolating the sought-for growth stimulating crystals. These were so potent that 1 part per million in a solution lengthened plant stems appreciably, and not in rice alone, but in other test plants: barley, cucumber, tobacco, and wheat.

Communication Barriers Delayed Recognition

Although a number of reports on Gibberella research appeared in Japanese language journals, up to World War II, the findings attracted

slight international interest because of the language barrier. Scientists in the United States knew about the earlier reports through abstracts in translation. These abstracts stressed Japanese concern with bakanae rice disease, a crop problem limited almost entirely to the Orient.

During World War II the communication barrier heightened. The Japanese published more Gibberella research reports, but these were not abstracted in the United States until 1950.

Post-War Advances

In 1950 the U. S. Army Chemical Corps Biological Laboratories first reported a research effort in the United States to use the Gibberella fungus to obtain a plant stimulator. Working on compounds affecting plants, Army scientists sought to include the growth stimulator which the Japanese called gibberellin A. Japanese scientists cooperated by sending a strain of Gibberella fungus known to give good yields of crystalline gibberellin A. The first American attempt to isolate gibberellin A yielded a substance which was potent but gummy.

The following year, the ARS Northern Utilization Research and Development Division, in Peoria, Ill., was asked to develop a reliable method for producing pure gibberellin crystals. This Division had developed a fermentation process for producing penicillin, and the new problem involved similar work. Scientists in the Division studied Japanese reports on gibberellin chemistry. They also obtained additional strains of the Gibberella fungus from England, where gibberellin research had also begun. When the ARS researchers isolated their first crystalline substance, they learned that they had a mixture of two gibberellins, both stimulating to plants, but chemically different. One was apparently the same as the Japanese gibberellin A. The other they tentatively called gibberellin X.

Meanwhile, British scientists isolated a gibberellin product, and called it gibberellic acid.

Researchers in the United States, Great Britain, and Japan reviewed their findings and reached these new conclusions:

* The Japanese gibberellin A was actually a mixture of 3 plant-stimulating chemicals. The Japanese renamed these gibberellins A_1, A_2, and A_3.

* The Japanese gibberellin A_1 was the same as the American gibberellin A.

* The Japanese gibberellin A_3 was the same as the American gibberellin X, and the same as the British gibberellic acid.

Chemical formulas for these three gibberellins are:

A_1 -- $C_{19}H_{24}O_6$

A_2 -- $C_{19}H_{26}O_6$

A_3 -- $C_{19}H_{22}O_6$

Tentatively, a British chemist has described gibberellin A3 (gibberellic acid, or X) as tetracyclic dihydroxy lactonic acid.

The Northern Utilization Research and Development Division succeeded in developing a dependable method by which 3-day fermentation yielded 12 grams of gibberellin crystals from 160 gallons of culture liquid. Scientists previously had such small amounts of pure crystalline gibberellin to work with that they could test few plants, and these sparingly. The marked expansion in production made more extensive experiments practicable, and many research agencies began experiments that they had wanted to try.

CURRENT TERMINOLOGY

The name gibberellin is a general term for any of the plant-stimulating substances produced by the *Gibberella* fungus. Research reports indicate that different strains of the fungus may produce chemically different gibberellins, and that some researchers have also obtained derivative types by experimental laboratory procedures.

The name gibberellic acid has gained wide use in describing the gibberellin also once known as A3 or X, and this is the gibberellin preponderantly produced at present, because it is the type most abundantly secreted by the fungus and the easiest to extract. Though products sometimes contain some amount of another gibberellin, they are often referred to as gibberellic acid for convenience. The effects of the gibberellins appear to be similar in the main, though research may eventually show that one or another has special potency for inducing some precise effect.

The name fusaric acid has been given to the growth-retarding substance which Japanese scientists extracted from the *Gibberella* fungus in 1934. This substance has been little used in research because it is extremely toxic to plants.

COMMERCIAL ADVANCES

Chemical manufacturers have shared in developmental research which has put gibberellin materials on a commercial production basis, and are sharing in research to develop specific uses for the products. Trademarked gibberellin products are increasingly introduced on the market, to be sold with garden supplies.

Thus far, gibberellin materials have been produced only from mass cultures of selected fungus strains--by fermentation and purification, involving complex equipment and procedures. When the products were first marketed about 2 years ago, the chemical was relatively expensive. Improvements in biologic processing have somewhat lowered the cost, and from a cost standpoint some use of these materials now appears practical. If it becomes feasible to manufacture this kind of plant stimulator synthetically from chemicals, this might be expected to simplify and therefore cheapen production further.

ARS PRELIMINARY SURVEY

A preliminary study of the responses of many kinds of plants to gibberellic acid was conducted at the Agricultural Research Center in Beltsville, Md., in 1955-56, mainly under greenhouse conditions.

Plants Selected

The plants selected for this survey included about 50 kinds--species, varieties, and hybrids, representing a wide range of field, horticultural, and forest crops.

Treatments Selected

Water solutions--ordinarily the most convenient means of using the chemical--were applied on plant stems, buds, flowers, or fruits, in selected spray, dip, and soak treatments. The gibberellic acid in these solutions ranged from 0.001 to 1,000 parts per million (p.p.m.).[1] Because the powdered acid is not readily water-soluble, a detergent consisting of polyoxyethylene sorbitan monolaurate[2] was added to facilitate mixing. In the stronger solutions, some alcohol was used also to increase solubility.

Lanolin paste was used in some experiments, partly to conserve gibberellic acid and also to compare the effects of paste with water solutions. Paste mixtures contained 0.01 to 1 percent of gibberellic acid in melted lanolin. This was spread at rates of 1 to 300 micrograms of the acid per plant on stems, buds, tubers, or roots.

Untreated Plants for Comparison

Throughout the experiments, groups of treated plants were compared with similar groups left untreated. Weight and measure records were taken on stems, leaves, roots, and other plant parts to learn the amount of change that was due to chemical stimulation.

Findings on Two Basic Points

The experiments showed that even the weakest treatments induced a change in some test plants, and whether the treatment was applied in a paste or liquid form made little difference.

Beyond this, the study provided information on two points basic to further work: What kinds of plants would respond to gibberellic acid, and what kinds of changes the chemical would induce.

Almost every kind of plant treated with the acid responded in some way. Gladiolus and onion were among the exceptional few showing no response to any of the test treatments.

The survey indicated that varieties within a species often respond similarly to gibberellic acid. But this cannot be relied on as a guiding rule, for some varietal differences were observed. For example, the same test treatment produced these striking differences in two rose varieties: Better Times produced more flowers of high quality with moderately long, 10-inch stems; whereas Golden Rapture grew undesirably long 3-foot stems and flower buds of only pencil size.

[1] One part per million is 1/10,000 percent.

[2] In this procedure, ARS scientists used Tween 20 as the detergent. Mention of this detergent does not constitute an endorsement by the U. S. Department of Agriculture of this product over similar products or a guaranty or warranty of the standard of the product.

Stem Growth Effects

The most pronounced stem lengthening occurred in young plants in the active growth stage. The stem lengthening was consistently of the kind characteristically induced by gibberellic acid--a lengthening of internodes, the sections of a stem between the nodes, or joints.

A doubling or tripling of height was common in treated crop plants, such as snap bean, soybean, eggplant, barley, corn.

Pinto bean plants, which are highly sensitive to gibberellic acid, provided a demonstration of different responses following treatments of different strengths: Given the weakest treatment, 0.001 p.p.m., young Pinto bean plants grew slightly taller than controls, and their growth spurt lasted 3 or 4 days; given 10 p.p.m., plants grew longer stems for 3 weeks; given 100 to 300 p.p.m., plants grew longer stems for a month or more. While increasing strength of these treatments prolonged the effect, the speed of growth was not increasingly faster. Stem heightening was most rapid at 1 p.p.m., and then with stronger solutions the rate of increased growth was progressively less--in this test plant.

Fast-growing stems had a tendency to be thinner at first and to continue thin if the dosage was strong. But with moderate dosage, some plants--particularly woody kinds--developed stems that became thicker than normal as growth advanced. A year after one treatment, young greenhouse seedlings of black walnut, willow oak, and loblolly pine had stems 40 percent taller than controls and twice as thick. (See Figure 1.)

Many plants take a leisurely time to resume growth when they are set out after a rest period in cold, dark storage. A faster start, which would prolong seasonal growth, would be particularly advantageous in areas where the growing season is short. Young willow oak, sugar maple, and red maple seedlings started growth 7 to 14 days earlier when treated with gibberellic acid after storage.

Some kinds of stimulated plants maintained a growth lead, whereas others did not. Young corn, for example, shot up 2 to 3 times as tall as corn untreated; but control corn plants later caught up in growth. A temporary gain, however, might serve its own purpose in some growing situations, such as speeding young plants past a stage at which they are ready prey for destructive organisms.

Several methods of treating potatoes with gibberellic acid were tried as aids in speeding growth. Cut pieces of seed potato, taken from storage and dipped in a water solution containing 100 p.p.m. of the chemical, sprouted no faster. On the other hand, young potato stems treated with the acid grew much faster than untreated stems.

Effects on Leaves

Temporary paleness in the green of developing leaves was common in young treated plants. Apparently, chlorophyll production could not compete strongly with the cell elongation and other growth processes spurred by the acid, all drawing on the nutrient supply. As a preliminary test of possible help from additional nutrients, minerals were added to the soil of some gibberellic acid-treated plants, and the green of young leaves did deepen.

Figure 1.--A favorable response to an experimental gibberellic acid treatment is illustrated by the 2-year-old loblolly pine at right. When this greenhouse plant was a year old, it was sprayed once with a solution containing 400 p. p. m. of gibberellic acid, and a year later it has a stem twice as thick as the untreated pine at left, and moderately taller also.

Leaf shape was altered in some treated plants. Some developed broader leaves; some developed leaves longer and narrower.

More abundant foliage was produced by some treated plants, such as spinach, turnips, and Brussels sprouts. The Pinto bean, with its marked sensitivity to gibberellic acid, stepped up its leaf area 56 percent after mild dosages in the range of 1 to 10 p.p.m. But in similar plants an overdose of 300 p.p.m. produced reverse effects. The developing leaves were smaller and thinner than normal. The adverse effect of an overdose of gibberellic acid on a tobacco plant is shown in Figure 2.

Figure 2.--Some common undersirable results of overdosage with gibberellic acid are illustrated by the two tobacco plants at right. A spray containing 200 p. p. m. of the chemical was applied to these plants when they were about a month old. The treatment proved too strong, as evidenced a month later when the plants displayed these long, spindly stems and narrow leaves. The untreated plants at left indicate typical growth.

A single mild spray treatment with gibberellic acid in September caused field-grown celery plants to grow leaf stalks three times as long and thick as controls. This treatment made the celery plants more susceptible to frost damage, probably because of an increase in succulence.

Effect on Fresh and Dry Weight

The above-ground parts of most treated plants were larger and heavier than those of untreated plants. Pinto bean and soybean plants showed 20 percent increase in fresh weight; 35 percent in dry weight. Celery increased 30 percent in fresh weight; 10 percent in dry weight.

Flower Production

Flowering was advanced 1 to 4 months in some treated plants, such as dahlia and Shasta daisy. These are plants that under greenhouse conditions ordinarily develop a rosette of low foliage and tend to remain at this stage for several months before sending out flower stalks. The acid's effect on these plants was to trigger flower stalk production, leading to early bud development, and thence to early flowering.

Just the opposite effect--retarded flowering--was obtained in another plant which does not have the rosetting habit: Young sweet pepper plants after treatment grew an excessive amount of foliage and flowered a month later than normal.

Possibilities of massing blooms for display were shown by such plants as the African violet and cyclamen, which have a growth habit of releasing a few buds at a time from dormancy, so that they flower over a long period. Following experimental treatment, these plants opened in about 3 weeks 2 to 3 times as many blossoms as the controls.

Dwarfing Overcome

A dwarf dahlia variety treated with 1 percent gibberellic acid paste grew stems that were much taller and also thicker. The leaves were separated by long internodes. Flowers opened 7 to 10 days earlier.

Seed Production in Biennials

Sugar beets and other biennials that did not have preliminary low temperature sent up seedstalks and produced seed when treated with gibberellic acid. This type of response indicated possibilities for inducing biennial plants to change their 2-year cycle of alternate crop and seed production.

Fruit Not Affected

Fruit development was not hastened by applying gibberellic acid to the growing fruit of bean, pepper, and tomato plants.

Nor did the acid speed the yellowing and softening of green bananas in storage, when the acid was applied to the fruit in a lengthwise strip of lanolin paste.

Dry Seed, Bulbs, or Corms Not Affected

Treatments that were applied to dry seed, bulbs, or corms did not usually speed their sprouting, or affect the subsequent growth of the plants.

Effect on Roots

Root development was frequently retarded while young stimulated plants were growing rapidly above ground. Apparently, the chemical

stimulated plants to channel upward a large part of their nutrient supply. It was learned that giving young plants a week or two of initial growth before applying a treatment was likely to be a wise precaution, since it enabled the plants to establish better roots. The possibility was seen that nutrient supplements might help to improve root growth and also the greening of foliage of gibberellic acid-stimulated plants. ARS scientists have since begun experimental work on fertilizer supplements used with gibberellic acid. (See page 16.)

FURTHER CROP PLANT RESEARCH

Aided by the greenhouse study of many test plants, ARS scientists are now directing further gibberellic acid experiments to selected crop plants and crop problems.

Though no recommendations or directions have yet come from these fact-finding studies, some indications are shaping up. There is real promise that gibberellic acid can be used to economic advantage with such crops as chrysanthemums. At the other extreme, tests on sugarcane have indicated no value in ordinary use of the chemical with this crop. A negative finding at this stage is not necessarily final, however. Other kinds of experiments or more knowledge could reverse a "no value" report.

Following are examples of this work, some done in greenhouses, some in the field at USDA field research stations, and some by cooperative arrangements at State agricultural experiment stations.

Chrysanthemums

Numerous gibberellic acid experiments have been conducted with greenhouse chrysanthemums at the Agricultural Research Center. Many test plants have demonstrated some desirable display effect or other potential economic advantage. Particularly encouraging is evidence that gibberellic acid can increase the range of tolerance to temperature for individual chrysanthemum plants, overcoming adverse environmental heat or cold. Temperature requirements of chrysanthemums are among the most costly aspects of producing this flower commercially.

Overcoming adverse temperature effects.--Development of the flower from the flower bud onward is ordinarily retarded in many varieties of chrysanthemums if the temperature falls below an ideal level of 60° F. at night. But gibberellic acid has enabled these varieties to bloom without the usual delay in a greenhouse as cool as 50° F. If this finding can be put on a practical basis, it will give growers a better solution to one of their economic problems. At present, it is costly to maintain a greenhouse at 60° F. just for chrysanthemums. Yet the alternative--of putting these plants in cooler greenhouses that suit other plants--is also costly because the chrysanthemums bloom so slowly that they occupy valuable space a long time.

In some other chrysanthemum varieties, flowering development similarly is retarded when the environment is too warm. This can occur in outdoor plantings when weather stays warm in autumn. The retarded blooming is also a common problem in greenhouses when chrysanthemums are grown under black cloth to give them a short day to induce blooming in summer. For these greenhouse plants, the black cloth becomes a heat trap. Gibberellic acid has enabled these varieties to flower satisfactorily in 80° F. environment.

Improved display effects.--Varieties of chrysanthemums that crowd their flowers in narrow club-formed clusters have been induced by gibberellic acid treatment to spread flower stalks apart for more pleasing display.

Flowering of chrysanthemums has been tailored in varied ways by test treatments. Some long-petal varieties have changed to an attractive pattern in which central florets form a short massed crest surrounded by the long petals.

Problems in developing practical treatments.--In gaining some wanted effect with gibberellic acid, stem lengthening is often a side-effect; and in chrysanthemum crop production, growers seek to avoid the cost and expense of staking long stems. Stem-lengthening as an objectionable side effect has been suppressed in some chrysanthemum experiments by finding the right adjustments of strength, timing, and placement of the treatment. Plants so treated have been induced to flower faster, for example, with little or no gain in stem height. A further possibility for suppressing stem heightening is to add another chemical to the gibberellic acid treatment--a chemical that can retard stem growth. This has been tried successfully with a quaternary ammonium compound known as Amo-1618. The two chemicals neutralized their influences on stem height.

Precise timing has proved important for gaining a wanted effect from gibberellic acid applied to chrysanthemums, and particularly during short day conditions. A demonstration of the importance of timing has been provided by treatments applied to one variety that requires for flowering 10 weeks of short days from the vegetative stage. These plants were most acutely sensitive to the stem heightening influence of the acid when sprayed several times in the third week of their short-day period. The same variety speeded lengthening of flower stalks when sprayed in the fourth week of short days. The same variety hastened flowering without stem lengthening when given a concentrated treatment in the seventh week of short days.

The complex procedure of managing gibberellic acid so as to induce a series of three desirable changes in a single plant has been tried with chrysanthemums, with success. This experiment was aimed at combining in one plant all of the changes that had been induced in separate plants during three stages of their short-day period (described in the foregoing paragraph). It was aimed also at keeping the stimulation moderate and gradual, so that the flowering plant would attain improved display value. A number of experimental plants were treated with gibberellic acid at varying strengths and at different precise time intervals before the successful result, shown in Figure 3, was achieved.

Varieties of chrysanthemums have differed so markedly in response to gibberellic acid that treatments evidently must be developed for definite varieties. One generalization observed is that Japanese and English varieties of chrysanthemums are acutely sensitive to gibberellic acid, and treatments as mild as 10 p.p.m. have damaged or killed these types. On the other hand, American varieties have usually tolerated stronger treatments.

Cotton

ARS scientists in California, Texas, and several other States are conducting gibberellic acid experiments on cotton, seeking several types of advantage.

Figure 3.--A series of gibberellic acid treatments of the right timing and strength induced three favorable changes in the experimental plant at right. This Vibrant chrysanthemum was sprayed at intervals from the fourth to the seventh week of short days. The treatments first heightened stems moderately. The continued treatments then lengthened flower stalks for better floral display, and finally speeded flowering. The control plant at the left shows typical growth, and stands about 12 inches high.

Boll retention improved.--The most promising finding from this cotton research, thus far, is that gibberellic acid is effective in increasing the ability of young bolls to cling to the plant. Shedding of bolls is a cause of considerable loss to growers. In this early work, the acid has been applied with a dropper to the base of each boll. Further work will be aimed at developing a practical method of application and at learning whether the treated plants yield a higher or lower quality of cotton or seed and whether the yields are larger or smaller.

Seedling growth effects less promising.--If young cotton seedlings could be induced to stand taller in their first 2 or 3 weeks of growth, this would have a number of advantages for growers. It would, for example, enable growers to start weed control earlier with post-emergence herbicides and flame weeding. However, neither treating cotton seed with gibberellic acid nor spraying young plants has given more than fair promise of advantage. With such treatments, young cotton has gained a little height in the first weeks of growth, but untreated plants rapidly caught up. Furthermore, the treated plants showed stem weakness. Test plants have been carried on to harvest stage to learn whether the early growth stimulation might result in heavier bolls or a total net gain. Some test plants have shown such gains, but the effects of the treatment have not been consistent.

Hydrangeas

Faster flowering.--Hydrangeas have been induced to develop blooms faster than normal after flower bud formation by spraying gibberellic acid on flower buds. These faster-developing flowers also became larger than untreated ones.

Improved symmetry.--Hydrangea tests have demonstrated an unusual use for the stem-lengthening effect of gibberellic acid--to rouse a laggard stem to catch up in growth with longer stems on the plant. This improved symmetry has been achieved by directing spray on the short stem at the level where a growth spurt is wanted.

Partial substitute for cold storage.--Gibberellic acid shows practical prospect of substituting for a third, or even half, of 6 weeks' storage at 40° F. or lower temperature which hydrangeas ordinarily require before flowering. Hydrangeas kept 4 weeks in cold storage and then treated with gibberellic acid have flowered satisfactorily. Actually, gibberellic acid can substitute for all of the cold requirement to bring hydrangeas into bloom, but plants thus treated have flowered with objectionable side effects, such as thin and misshapen leaves and sepals.

Influence of old leaves.--A peculiarity of hydrangea plants, which can interfere with their response to gibberellic acid, is the fact that their old leaves appear to contain some substance which blocks growth during dormancy. Having served their purpose, these old leaves drop off during dark, cool storage conditions, enabling the plant to resume growth when the normal cold period is ended. Dormant hydrangea plants treated with gibberellic acid have not been roused early from dormancy so long as these old leaves remained on the plants. Removing the low-growing old leaves has overcome the block.

Stone Fruits

Peach trees.--Since gibberellic acid is one of the few chemicals that have shown any influence on plant dormancy, it provides a much-wanted tool for experiments with fruit crops, notably peaches. Peach trees in the South start growth late and irregularly following unusually warm winters, because of insufficient cold to break dormancy, and crop failure may result. In initial experiments with gibberellic acid applied to peach trees exposed to insufficient cold, ARS scientists in Georgia found that treated branches did show rapid development of leaf and flower buds, but by crop time these branches bore no more fruit than untreated branches.

Sweet cherry and peach seed.--Poor germination of sweet cherry seed is a problem for nurserymen, especially in producing seedlings of early maturing varieties. ARS and Washington Agricultural Experiment Station scientists working cooperatively have tried various methods of combining gibberellic acid with seed management and have gained promising results. The best results have been obtained by preventing the sweet cherry seed from drying out and providing 2 to 4 months of moist stratification in soil in flats, followed by soaking the seed in gibberellic acid. Thus used, the gibberellic acid has not only reduced losses but has shortened the stratification process by about 3 months, making it possible to start seedlings in the same season that seed are produced. Preliminary experiments with peach seed germination at Fort Valley, Ga., have given somewhat inconsistent results, but gibberellic acid does show possibilities for substituting for part of the cold requirements of peach seed.

Sugar Beets

A lack of seed of sugar beet varieties adapted to early plantings and mild winter culture prevents many growers from planting varieties that would give them best sugar yields. This difficulty remains from the partial solution of an older problem: Common varieties of sugar beets, when grown in mild winter climates, tend to bolt--that is, to go to seed--and seriously cut sugar yields. To aid these growers, breeders have developed sugar beet varieties increasingly resistant to bolting. But, paradoxically, the more nonbolting the variety, the more difficult is seed production. Highly nonbolting varieties have required 3 months or more of preliminary moderate cold below 65° F. to produce a seed crop, which poses a geographic problem. These varieties have not gone to seed in the West and Southwest where sugar beet seed are commercially produced. Some colder areas of the United States could provide the required amount of cold exposure for seed production, but here an economic obstacle is met. In these areas, beets left in the ground would freeze; and Old World methods of digging roots for seed, storing them over winter, and transplanting in spring for a seed crop would be too costly in this country's economy.

A chemical substitute for cold.--To learn whether gibberellic acid could substitute for part of the cold requirement for a sugar beet seed crop, ARS scientists, working cooperatively with the Colorado Agricultural Experiment Station, have experimentally treated a highly nonbolting sugar beet variety. Young greenhouse plants were allowed varying periods of cold and then sprayed with four successive treatments of the acid. With this chemical aid, plants which had only 43 days of cold developed mature and viable seed in 25 weeks. This number of days of moderate cold could be provided in parts of the country where sugar beet seed are a commercial crop. Field trials will show whether the greenhouse results can be applied in practical growing conditions.

A possibility that gibberellic acid differently applied might enable nonbolting sugar beet plants to produce seed without any preliminary cold has been tested at a USDA field research station in Utah. In this experiment, the acid was sprayed on growing parts of sugar beet plants of a number of varieties. Most of the bolt-resistant varieties sent up seedstalks, but their flowering and seed production were so erratic that the treatment was evidently not a dependable substitute for total cold in producing seed.

Negative results in speeding growth.--Gibberellic acid has been tried as an aid in speeding the initial growth of sugar beet crops. In these tests, by ARS scientists in cooperation with Michigan Agricultural Experiment Station, sugar beet seed and also seedballs were soaked in solutions containing amounts of gibberellic acid up to 10,000 p.p.m. None of these treatments speeded germination. Only the strongest treatments led to stem lengthening of the resulting plants in their early growth.

Sugarcane

Sugarcane experiments by ARS scientists in Louisiana have not indicated that gibberellic acid can be used advantageously by sugarcane growers in normal crop production. Treated plants grew 20 to 25 percent taller but somewhat thinner than controls. Treatment did not increase sugar yield. Furthermore, the taller and thinner stalks were subject to breakage when the plants were sprayed with the acid late in season.

There is a possibility that gibberellic acid might usefully spur growth of sugarcane effectively under adverse conditions, such as drought and cool weather. Tests along this line are planned.

Turfgrasses

Gibberellic acid has been tried for speeding turf production in some ARS experiments. Superintendents of public grounds and golf courses and others who have a problem of establishing a turf cover in new areas would welcome some means of speeding grass-seed germination, or speeding seedling growth--particularly runner production. Once a planting is well established, turf growers generally prefer that the grass grow slowly, to keep down maintenance costs.

Results of these experiments have not indicated that gibberellic acid would be of extensive value for speeding the process of getting a new turf cover. The chemical may still prove helpful in some special grass-growing situations, such as breaking dormancy to give grass an earlier growth start or to enable the grass to compete more favorably with weeds.

For grass-seed testing, ARS scientists selected bluegrass seed, which germinate slowly. Seed of two bluegrass varieties were treated with the acid before planting. The seed did not germinate any faster than untreated seed. Nor was the subsequent growth of the seedling grass speeded.

For tests of seedling grass plants, bentgrass, zoysia, bermudagrass, and several other types were selected, and these were treated with several strengths of gibberellic acid in the greenhouse and later in the field. Under field conditions, bentgrass grew faster after being treated with gibberellic acid at the mild level of 10 p.p.m. Field-grown zoysia grew no faster

except with the strong treatment of 500 p.p.m., and even at this strength the results were not favorable. Zoysia grew taller but the foliage yellowed, and the wanted increase in runner growth failed to develop. Bermudagrass responded somewhat similarly to zoysia, and in general showed no all-round improvement.

FERTILIZER SUPPLEMENT RESEARCH

ARS scientists have started a series of studies on practical possibilities of combining fertilizer supplements with gibberellic acid. It is evident that young plants stimulated with this chemical are often handicapped in root and foliage development--even when the soil nutrients and fertilization are such as would ordinarily assure a desirable balanced growth. It seems possible that a supplement of the right nutrients might improve the root development and greening of young stimulated plants, and perhaps even improve their later growth and yields.

In this new fertilizer research, each successive study has provided some basic information, although limited to a single test plant, a single type of soil, and greenhouse conditions. Within these limits, the results so far are mainly encouraging.

Compatibility and Storage Life Favorable

The initial experiments were aimed at gaining information on two related questions on which combined use of gibberellic acid and fertilizer, both in solid forms, would depend:

1. Can gibberellic acid blend compatibly with dry fertilizer materials, not losing effectiveness?

2. Can gibberellic acid combined with solid fertilizer salts retain its effectiveness during reasonable periods of storage?

Tests with salts singly.--Fifteen salts--forms of nitrogen, potassium, and phosphate--were combined singly with gibberellic acid in several strengths. The mixtures were stored in two atmospheric conditions, dry and humid, for 5 periods ranging from 7 to 112 days. For further comparison, some test mixtures were made up and applied to plants on the same day. The test plant throughout these experiments was the Pinto bean, which responds quickly to the acid. Each test mixture was applied in water solutions at a rate providing a plant with 1 p.p.m. of the acid. For experimental precision, solutions were sprayed with an atomizer on the trifoliate leaves, which form soon after the first two developing leaves. The criterion of effectiveness was the amount of stem lengthening measured 5 days after treatment, checked against the stem height of untreated plants.

In general, gibberellic acid proved compatible with each of the fertilizer salts, and adequately stable in all combinations for all periods of storage. Some nutrient salts appeared to reinforce the gibberellic acid, so that stem height gains were greater; addition of some salts slightly lessened height gains; and some salts had no influence on this effect of the acid.

The possibility was ruled out that a nutrient alone might have caused the same stem height gains. Each salt, without gibberellic acid, was applied to test plants, but none spurred stem growth noticeably in so brief a time as 5 days.

Tests with 2 complete fertilizers.--Two solid mixed fertilizers were combined with gibberellic acid and tested in the same way as the 15 individual salts. The mixed fertilizers contained widely different proportions of nitrogen (N), phosphoric oxide (P_2O_5), and potash (K_2O): 20-20-20 and 10-52-8. In these preliminary trials with complete fertilizers, the gibberellic acid was somewhat less effective than with most of the single-nutrient salts. However, the plants gained enough to indicate some practical use, perhaps by gardeners and growers of ornamentals.

Stability of Gibberellic Acid in Solution

A storage test on gibberellic acid in plain water solution showed that after 14 days a solution was still highly effective when applied to test plants. This indicates possibilities for its use in combination with liquid fertilizer materials. Liquid fertilizers are generally produced for shipment over short distances, and therefore a moderate stability of gibberellic acid would be adequate.

Soil-Applied Gibberellic Acid Effective

A next step was to determine whether the Pinto bean plant could obtain and use gibberellic acid from the soil. Soil applications of gibberellic acid have rarely been tried, but success with them would be essential to any practical application with solid fertilizer.

The soil used was an acid, sandy type, and ordinarily good fertilization was established before the experiments started. With this soil, and under greenhouse conditions, the results continued favorable.

Each half-pound of test soil was treated with solutions (5 milliliters) containing 1, 10, and 100 p.p.m. of gibberellic acid. Pinto bean plants 10 days old were then transplanted into soil given each treatment. When stem heights were measured 5 days later, the plants in treated soil stood taller than those in untreated soil. The tallest plants--2 to 3 times taller than controls--were in soil treated with 100 p.p.m. of the acid.

Gibberellic Acid Stable in Soil

Evidence was also obtained that gibberellic acid may remain effective in a soil for several months. For this test the acid, sandy soil was treated with 10 and 100 p.p.m. of gibberellic acid in solutions. A succession of three Pinto bean crops was planted. Each crop was allowed to grow 15 days. Even the third crop showed stimulation effects though the acid had been in the soil nearly 100 days.

A Reminder--This Work Preliminary

ARS scientists emphasize that these experiments are preliminary and are not a basis for recommendations as to the use of fertilizer-gibberellic acid mixtures.

MANAGEMENT POINTERS AND PRECAUTIONS

From present knowledge, some general pointers and precautions for management of gibberellic acid in spray or paste forms can be outlined:

Strength of treatment is always important, and needs to be adjusted to the plant species and sometimes the variety, and also to the stage of the plant's development. For young and delicate plants, suitable solutions are likely to be in the range of 1 to 10 p.p.m.; for young seedling trees, perhaps somewhat stronger; for mature and sturdy plants, possibly up to several hundred. In occasional instances, plants that have failed to respond to mild solutions have produced a wanted effect from stronger treatments.

Overdosage is always to be avoided. Overstimulated plants generally produce meager flowers, fruit, or other expected yields. Moreover, overdosage induces rank growth and may damage or kill a plant.

Solutions made from a commercial formulation should be prepared in accordance with the manufacturer's directions. Starting with the pure crystalline powder, ARS laboratory workers follow this procedure: First make a relatively concentrated solution by weighing out 1 gram of gibberellic acid and completely dissolve this in 4 or 5 milliliters of 95 percent ethyl alcohol. Add 1 milliliter of a type of detergent used in washing dishes and sold under trade names--a type chemically composed of polyoxyethylene sorbitan monolaurate.[3] Dilute the concentrated mixture of acid-alcohol-detergent by adding it slowly to 1 liter of water (preferably warm), stirring vigorously. This preparation contains 1,000 p.p.m. of gibberellic acid. A range of dosage levels can be prepared by diluting it in a water-and-detergent mixture made by dissolving 40 to 50 drops of the detergent in 1 liter of water.

Paste for stem application can be prepared as follows: For 1 percent paste, weigh 12.5 milligrams of gibberellic acid and place in a small vial. Add about 7 drops of the same type of detergent used in making solutions, and warm gently to dissolve the acid. Add 1 gram of melted lanolin and stir thoroughly until a creamy paste forms.

Effectiveness of a treatment is usually evident in a short time. Young and succulent plants in the greenhouse have shown measurable growth changes in 24 hours after a spray containing as little as 0.01 p.p.m. The lasting effect of a treatment is fairly brief. Spray treatments have usually affected plants no more than 2 or 3 weeks. Paste applications have sometimes induced changes for a month or longer.

Repeating treatment is sometimes practical. In some plant situations, several mild doses have induced a wanted effect when the same amount of the acid in one dose would be toxic. In other situations, renewing a treatment has prolonged a wanted stimulation or given added improvement.

A pale green is the color most common in the young developing leaves of plants stimulated by gibberellic acid. If the plant has not been overdosed, greening usually deepens when the growth spurt is over.

Root development tends to be retarded when a treated plant is spurred to grow rapidly above ground. Allowing a young plant or a transplanted one a week or 2 to establish favorable root development before gibberellic acid is applied is likely to be a wise precaution.

[3] See footnote 2 on page 5.

Favorable growing conditions of soil fertility, moisture, and light are important to plants stimulated to faster growth by gibberellic acid. The acid can substitute for some light requirements, but not for plant nutrients. More fertilizer, not less, may be required.

If any toxic residue should be left on plants by gibberellic acid, use of this chemical for food and feed crops would depend on tolerances established by the U. S. Food and Drug Administration. Chemical manufacturers who have made some tests have thus far found no evidence of residues or toxicity risk. If this evidence is conclusively established, there will be no need for official regulations regarding safety. For the time being, if gibberellic acid is applied to food and feed plants, it should not be used in such a way that any residue is left in the food or feed as consumed. For a statement on the position of the U. S. Food and Drug Administration on the matter of residue, as of June 12, 1958, see the footnote below.[4]

GIBBERELLIC ACID AND PLANT DISEASES

Since gibberellic acid is derived from a fungus that damages Far Eastern rice crops, questions are sometimes asked as to whether the bakanae disease occurs in the United States, and whether the use of gibberellic acid carries any risk from a plant disease standpoint.

Bakanae Disease a Minor Problem in U. S.

Gibberella fujikuroi or some closely related species has been present in the United States, probably for many years. But apparently this country's environmental conditions are not favorable to the spread of this plant parasite. Its damage to rice plants in this country is so slight that control measures would not be worth their trouble or cost. In any case, use of gibberellic acid would have no connection with such fungus infections observed in plants, for the reason described in the following paragraph.

[4] The following statement is quoted from a communication from the U. S. Food and Drug Administration, of June 12, 1958:

"The reports available to us of toxicity studies of the gibberellins have not shown evidence of toxicity but we are not aware of any tests which have resolved all questions of their safety, and we do not know of any tests demonstrating conclusively that they are harmless substances. In the absence of such conclusive evidence of harmlessness, we do not regard gibberellic acid as suitable for general application to food or for use in food crop production where there is any question of a residue remaining in the food as marketed.

"Evidence has been submitted to us, obtained by an analytical method sensitive to 0.01 ppm, indicative that the following uses do not give rise to any residue in harvested crops.

"1. Treatment of the seeds of lima bean, snap bean, soya bean, and pea at the rate of 0.5 gram per 100 pounds, to promote rapid emergence of the seedling.

"2. Dipping seed potatoes in a 1 ppm solution to break dormancy.

"3. Spraying Thompson Seedless and Black Corinth grapes at quarterblossom stage, with concentrations between 5 and 50 ppm, at the rate of from 5 to 50 grams per acre, to improve size of fruit.

"We have expressed ourselves as having no basis for objection to the uses of gibberellic acid and gibberellins listed above.

"Similar studies of the residue consequence of other prepared uses of these substances have come to our attention but, in our opinion, have not been sufficiently convincing to overcome reservations we deem prudent at this time. We have stated as a generality, however, that if a proposed use does not in fact result in residues in a food crop, we would raise no objection to such use."

Why Gibberellic Acid Cannot Spread Plant Disease

Although a plant overdosed with gibberellic acid may develop the rank and straggling growth of bakanae-diseased plants, the symptoms are due to overstimulation and malnutrition--conditions which cannot be transmitted. Only some live part of the Gibberella fungus can spread bakanae disease or its damage. In the biological production of the gibberellic acid crystals, the processing destroys any live organisms present.

PHYSIOLOGICAL PROCESSES

The role of gibberellic acid in nature and the manner in which the substance works are still far from clearly understood, but plant experiments are providing clues and fragmentary information, such as the following:

An unusual amount of elongation of cells has been observed in microscopic examination of plant tissues affected by the acid. It is possible that cells divide at an increased rate. The acid appears to work as an unblocking agent for cell development.

The fact that gibberellic acid can substitute for part of the light requirements of plants is a significant clue to one type of its action. Apparently certain wave lengths of light and gibberellic acid, operating through different mechanisms, can produce similar observable effects--somewhat like a regular key and a master key for opening a locked door--so that either unblocking device permits activity of the plant substance or substances that control seed germination, flowering, and other photoregulated processes.

Gibberellic acid has not yet been definitely classified among the known types of substances in plants. Some scientists have considered its action most similar to that of a plant hormone, a substance produced in a plant for use elsewhere in the plant. Other scientists have compared it to a plant vitamin, serving as an active agent in vital metabolic processes. That gibberellic acid may serve as an antibiotic is considered unlikely, since it has shown no capacity for directly attacking or destroying living organisms.

There is some evidence that gibberellic acid represents a type of plant stimulator which occurs widely in the higher orders of plants. ARS scientists and others have detected the presence of somewhat similar agents in bean seed, pollens, and other plant sources.

RESEARCH PROSPECT

Research on the controlled use of gibberellin products has made rapid strides in a few years, following slow early development. But it is obvious that much work remains to be done in determining their place in agriculture, and in developing dependable treatments for growers' use.

Besides experimental work on specific crop applications, future research may be expected to seek answers to a varied range of questions. For example:

* How does gibberellic acid induce its varied effects on plants?

* Does it change the enzyme activity, sugar content, or other characteristics of plants, affecting their value?

* Are there differences in the gibberellins--such as in potency for inducing some effects--which may indicate specialized uses?

* Can formulations be improved for economy, perhaps by increasing the absorption of the chemical by plants?

* Are tolerances indicated for safe use on food and feed crops, and if so, what are they?

Recognition of a type of natural plant regulator so complex and potent as the gibberellin substances opens up many avenues for plant research, pointing to new knowledge of plant processes and new controls over plant production.

Growth Through Agricultural Progress